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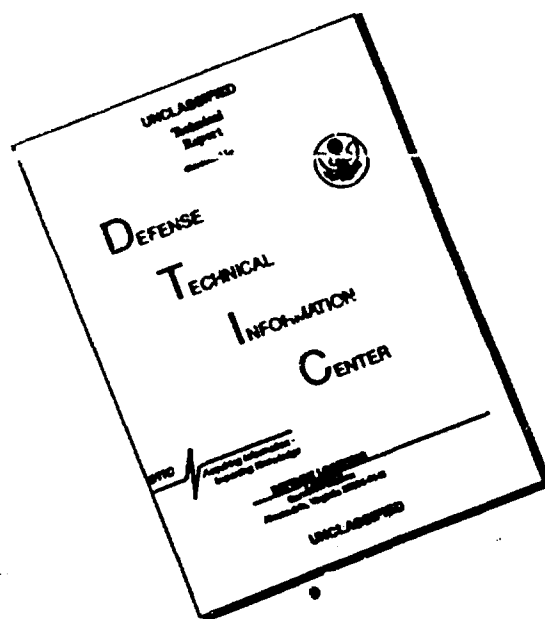
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13. ABSTRACT (Maximum 200 words)

Four lines of experimentation have been carried out. In the first set of experiments, we have tested and rejected a two-process model of visual attention allocation. The PI has proposed an alternative perceptual sampling model and performed stochastic simulations of the model to show that it can account for certain aspects of human performance in cued visual search tasks. In the second and third set of experiments, the PI has found that a common mechanism may underlie the perception of bistable apparent motion and the capture of visual attention in certain visual search tasks. In particular, the appearance of a new perceptual object in the visual field captures attention and this may influence how object identity is assigned in apparent motion perception. In the final set of experiments, the PI has examined the possible influence of factors influencing figural identity on the perception of bistable apparent motion. Preliminary results suggest that grouping by spatial proximity can modulate the assignment of motion correspondence in apparent motion perception.

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"Stochastic Models of Attention and Search"

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Summary

Four lines of experimentation have been carried out. In the first set of experiments, we have tested and rejected a two-process model of visual attention allocation. The PI has proposed an alternative perceptual sampling model and performed stochastic simulations of the model to show that it can account for certain aspects of human performance in cued visual search tasks. In the second and third set of experiments, the PI has found evidence that a common mechanism may underlie the perception of bistable apparent motion and the capture of visual attention in certain visual search tasks. In particular, the appearance of a new perceptual object in the visual field captures attention and this may influence how object identity is assigned in apparent motion perception. In the final set of experiments, the PI has examined the possible influence of factors influencing figural identity on the perception of bistable apparent motion. Preliminary results suggest that grouping by spatial proximity can modulate the assignment of motion correspondences in apparent motion perception.

Status of the Research

This report describes the technical progress achieved in my project, "Stochastic Models of Attention and Search," which is supported by AFOSR Grant F49620-92-J-0186.

Tests of a two-process model of visual attention allocation
(Johnson & Yantis, submitted)

We have carried out experiments and simulations in order to explore the properties and consequences of a two-process model of visual attention allocation. This work is described in detail in the enclosed manuscript, which has been submitted for publication to the *Journal of Experimental Psychology: Human Perception and Performance.*
In the experiments, subjects detected the presence or absence of a prespecified target element appearing in an array of four elements. A spatial cue appeared 200 ms before the onset of the display, indicating a location in the upcoming array. In separate blocks of trails, the cue was 100% valid, 50% valid, or 25% valid with respect to predicting the location of the upcoming target. In the 100% valid condition, the cue was completely predictive of the target's location, and in the 25% valid condition, it was independent of the target's location. In the 50% valid condition, the cue provided an intermediate degree of predictive validity. We were interested in testing an attention-allocation model in which subjects could allocate perceptual samples to spatial locations according to the information provided by the cue. According to the model, samples are taken at a location in proportion to the probability that that location contains the target. Evidence about the identity of the element in each location accumulates as a random walk over time, with evidence accumulating more rapidly (i.e., a higher drift rate in the random walk) for locations from which a larger number of perceptual samples have been taken.
The predictions of this parallel model were compared to those of a serial probability-matching model (Jonides, 1983). This model holds that observers may select in advance of each trial one location to which they direct their attention, or they may divide their attention over the entire display; subjects' selection strategy is assumed to vary from trial to trial according to the location and predictive validity of the cue. If the cue is 100% valid, observers always attend first to the cued location, and if the cue is only 25% valid,

the observers ignore the cue. When the cue is 50% valid, observers attend to the cued location on 50% of the trials and they distribute their attention evenly within the display on the remaining trials. According to the model, the reaction time distribution from the 50% valid condition should be a mixture of the distributions from the 100% valid and 25% valid conditions, respectively. Although the mean RT across conditions was consistent with the mixture prediction, a more complete distributional analysis (Yantis, Meyer, & Smith, 1991) ruled out the mixture hypothesis, thus undermining the viability of the serial probability-matching model.

We assessed the viability of the parallel perceptual-sampling model by running stochastic simulations of the model under the conditions used in the experiments. In the simulations, perceptual samples were allocated to spatial locations according to the validity of the cue, and perceptual evidence accumulated at each location in a random walk until a criterion amount of information for the target was acquired (information can be interpreted as perceptual features of the elements to be identified). The simulations yielded reaction-time distributions whose shapes and relative positions were compared to those obtained from human subjects. The simulations suggest that the parallel perceptual sampling model provides a viable alternative to the serial probability-matching model.

Object continuity in visual attention and motion perception
(Yantis & Gibson, forthcoming)

We have recently argued (see Yantis & Hillstrom, in press) that the appearance of a new perceptual objects in the visual field appears to capture visual attention. Experiments from our lab over the last several years had shown that the abrupt onset of a visual element captures attention; Yantis and Hillstrom, using equiluminant visual elements, found that it was not the luminance increment accompanying these appearances that was responsible for attentional capture, but the appearance of a new perceptual object. In the experiments described below, we sought to further explore the hypothesis that the visual system is predisposed to attend to the appearance of new perceptual objects. The goal is to link the phenomenon of attentional capture to the perception of group and element motion in the Ternus (1939/1926) display.

There are many versions of the Ternus display; I will describe one common one here. Two elements (e.g., disks) are displayed in a subset of three predetermined locations in the visual field (see Figure 1a). The three locations are horizontally arrayed about 1 degree of visual angle apart. In frame 1 of the display, lasting 200 ms, one element appears in the right location and the other object in middle location. In frame 2, also 200 ms in duration, the objects occupy the middle location and the left location. There is a brief blank interval (the interstimulus interval or ISI) between frames. Usually several such cycles are presented. The Ternus display is perceptually ambiguous: it can be perceived as involving either element motion (the element that begins on the right hops end to end over the stationary element in the middle location) or group motion (the two elements move back and forth together, as a group, so the identity of the element in middle location switches back and forth from one frame to the next). Figure 2 illustrates the motion correspondences under each type of percept.

The probability that observers perceive group motion depends on the magnitude of the ISI (see function labeled "No Occluder" in Figure 3): at short ISIs (less than about 10 ms), element motion is almost always perceived, and at long ISIs (more than about 100 ms), group motion is almost always perceived. The probability of perceiving group motion

increases monotonically between 0 and 100 ms with the exact location and slope of the psychometric function depending on factors like the size of the objects, their spatial separation, and their duration.

One can view the perception of the Ternus display as reflecting the parameters that determine what constitutes a perceptual object. If the duration of the ISI is long enough, then the perceptual continuity of the object in the middle location can be disrupted, allowing a change in the identity of that object, which is required for group motion to be perceived (see Figure 2, top). In contrast, if the duration is quite short, then that object's identity remains intact, and it can only be interpreted as a single, coherent, continuously-present perceptual object, leading to the perception of element motion (see Figure 2, bottom). If the ISI at which the transition between element-motion perception and group-motion perception in the Ternus display represents the duration required to disrupt the continuity of a perceptual object, then that same interval might also be sufficient, when inserted into an element in visual search, to capture attention (recall that attention is captured when a new perceptual object appears).

To test this idea, we have run several visual search experiments in which one element in the visual display is briefly erased and redisplayed during the trial (Figure 4). The duration of the gap varies over the same range as the ISIs in the Ternus display. Attention is captured in this experiment to the extent that the duration of the gap in the target element disrupts the object representation (see Figure 5): if the duration of the gap is very short, then it does not capture attention (attentional capture is indexed by the relative slope of the display-size function: flat or very shallow slopes indicate complete attentional capture, steep slopes indicate the absence of attentional capture). If the duration of the gap is very long, then it captures attention almost completely (i.e., the slope of the visual search function is near zero when the target is the element exhibiting a gap), and when the duration of the gap has an intermediate duration, then capture is partially successful. The timecourse of attentional capture is similar to the timecourse of the transition from element to group motion perception in the Ternus experiment. This result suggests that a common mechanism may underlie attentional capture in my visual-search task and the perception of element and group motion in the Ternus display.

Perceptual objects, occlusion, and motion perception
(Yantis, in preparation)

Another series of experiments that we are currently conducting also concerns the possible role of object representations in the perception of apparent motion in the Ternus display. Two classes of explanation for the bistability of motion perception in the Ternus display have been advanced. The first, which I will term the *two-motion-systems account*, holds that there exist two types of motion detectors in the visual system, the so-called short-range and long-range systems. The short-range system responds to small spatial displacements over short temporal intervals; the long-range system responds to all other types of motion. Pantle and Picciano (1976) suggested that this distinction may account for the bistability of the Ternus display: according to this account, the short-range system detects the absence of motion in the middle element at the short ISIs, leading to the perception of stability in that element. This in turn yields motion correspondences that are consistent with element motion. At longer ISIs, the short-range system is no longer active, so it can no longer signal stability in the middle element; this leads to motion correspondences that are more consistent with group motion.

A different type of explanation, which I will term the *persistence account*, has been advanced by Breitmeyer and his colleagues (e.g., Breitmeyer & Ritter, 1986). According to this account, visible persistence of the middle element in the Ternus display supports continuity in that element, so that it is not available for correspondence matching with the other element (see Figure 2, bottom). At longer ISIs, persistence of the middle element has decayed below threshold, and so when Frame 2 appears, the element appearing there will be perceived as phenomenally distinct from the element in that location in Frame 1 (Figure 2, top). This in turn makes it available for correspondence matching with the leftmost element in Frame 1, yielding group motion. Breitmeyer and colleagues have supported this claim by showing that the appearance of group and element motion is affected by factors that are known to affect the duration of visible persistence (e.g., the size and contrast of the elements).

The present experiment arose from recent proposals concerning object-based theories of visual attention (e.g., Kahneman, Treisman, & Gibbs, 1992; Kanwisher & Driver, 1992). According to these accounts, the representational basis for visual selection is not spatial location but preattentively defined perceptual objects. Recent evidence suggests that the appearance of a new perceptual object in the visual field captures attention, and that the object tokens involved are also responsible for correspondence matching in visual apparent motion tasks. To check this, the following experiment was conducted.

Observers viewed standard Ternus displays like the one depicted in Fig. 1a on some trials, and Ternus displays as shown in Fig. 1b on other trials. In the latter displays, which are termed "occluded Ternus displays," segments of the surrounding rectangle above and below the middle location are removed during the ISI. This produces two vertically oriented illusory contours which support the perception of a "virtual occluder" covering the middle location of the Ternus array.

The probability of group motion reports as a function of ISI for the occluded Ternus display (as in Figure 1b) is shown in Fig. 2 as the function labeled "Occluder"; the function labeled "No Occluder" (discussed earlier) shows performance on trials in which there was no occluder (as in Figure 1a). The main result is that the location of the transition from element motion perception to group motion perception is centered at about 40 ms for the standard display and much longer for the occluded display.

This finding can be explained by assuming that the occluder prolonged the phenomenal persistence of the middle element by providing an "explanation" for its disappearance: the element did not disappear, it was merely occluded (in the developmental literature, studies of object permanence in infants have yielded conceptually similar phenomena; e.g., Spelke, Breinlinger, Macomber, & Jacobson, 1992). Consequently, the element that was occluded still "persisted" during the ISI, and its continuity lead to the perception of element motion even at very long ISIs. Because its phenomenal persistence was prolonged, when the center disk physically reappeared, it was perceived as being the same object as in Frame 1, even though its physical absence was long enough for any trace of visible persistence to have faded. The effect of the virtual occluder on the perception of group and element motion cannot be explained by straightforward appeals to either the two-motion-systems account or a low-level version of the persistence account. Instead, a new, object-based account appears to be required.

This result is still tentative and requires further empirical verification. However, its implications for the unification of explanations for apparent motion perception and visual attention, like those for the experiments described in the last section, are intriguing.

Perceptual grouping and the perception of bistable apparent motion (Ternus) displays
(Kramer & Yantis, in preparation)

It has been known for a long time that apparent motion perception is insensitive to the form of the objects rendering the motion. For example, in standard two-element apparent motion, if one of the elements is a red square and the other a blue circle, the perception of apparent motion is as compelling as when both elements are red squares. This finding has led some investigators to claim that apparent motion is computed before any figural properties are computed (e.g., Kolers, 1972).

In this series of experiments, we tested one aspect of this claim by examining whether perceptual grouping by proximity could influence the perception of element and group motion in a Ternus display. If figural properties of a display are in fact computed after a motion signal is extracted, then one would not effect perceptual grouping to influence motion perception in a Ternus display. We implemented the test with displays like the one shown in Figure 6. In each panel, two displays are shown, labeled "1" and "2"; these are the two frames of the Ternus display, with a blank interstimulus interval of variable duration placed between them. Panels A and B show conditions in which the Ternus display is embedded in a context. In Figure 6A, the context produces strong vertical grouping, and in Figure 6B, the context produces strong horizontal grouping. If grouping does affect motion perception here, then we would expect to observe more element motion in conditions like Figure 6A than those like Figure 6B, because the context in 6A should serve to "anchor" the middle points in place. Figures 6C and 6D represent control conditions without context, used to control for variations in horizontal separation in Figures 6A and 6B. If the claim that figural effects are computed after the motion signal is extracted is correct, then we would expect displays like Figure 6A to produce psychometric functions like those in Figure 6C.

Figure 7 shows the results from one representative subject in this experiment. The four function labels (A, B, C, and D) correspond to the four display types shown in Figure 6. There is a small effect of spacing (compare functions C and D), replicating previous findings. The most dramatic effect, however, is the comparison between function A, with vertical grouping and where almost no group motion is perceived, with condition C, with the same horizontal spacing but no context.

Clearly there is a strong effect of grouping on bistable apparent motion perception. So the claim that figural effect come after motion computations must be modified and possibly abandoned. We are continuing to run experiments along these lines and to develop a coherent theoretical account of the empirical effects illustrated in Figure 7.

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Kramer, P., & Yantis, S. Perceptual grouping and the perception of bistable apparent motion. In preparation; to be submitted to *Vision Research* or *Spatial Vision*.

Collaborators

Douglas N. Johnson, former graduate student. PhD, Johns Hopkins University, 1992. Dissertation entitled "Representation and item-specific learning in lexical decision."

Bradley S. Gibson, postdoc. PhD, University of Arizona, 1992. Dissertation entitled "Representations of shape in memory."

Anne P. Hillstrom, graduate student.

Peter Kramer, graduate student.

Professional Presentations and Interactions

Member, Perception and Cognition Research Review Committee, NIMH, Feb 93 meeting.

Hillstrom, A. P., & Yantis, S. (1992, April). Attentional capture by visual motion. Paper presented at the 62nd Annual Meeting of the Eastern Psychological Association, Boston.

Yantis, S., & Hillstrom, A. P. (1992, November). Stimulus-driven attentional capture. Paper presented at the 33rd Annual Meeting of the Psychonomic Society, St. Louis.

Yantis, S. (1992, December). Mechanisms of human visual attention: Bottom-up and top-down influences. Invited paper presented in the Computational Models of Visual Attention Workshop at the 6th Annual Conference on Neural Information Processing Systems, Vail, Colorado.

Yantis, S. (1993, June). Visual attention and perceptual objects. Invited tutorial presented at the SISSA Theoretical Cognitive Neuropsychology Seminar on Attentional Processes and their Disorders (A. Caramazza & T. Shallice, organizers), Trieste, Italy.

(a) standard (b) occluded
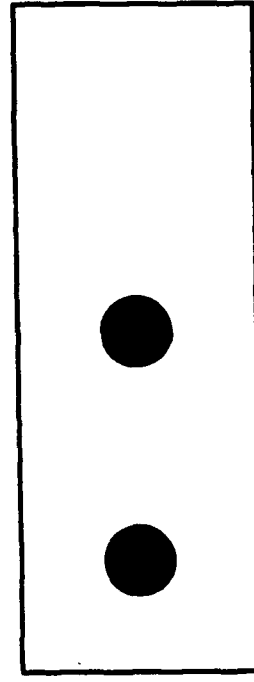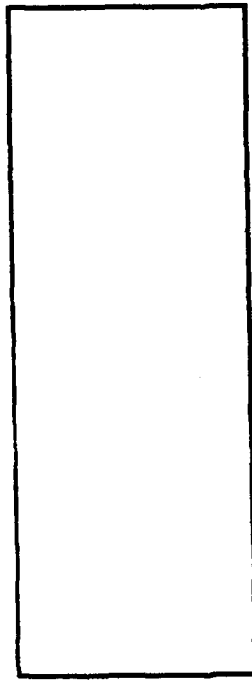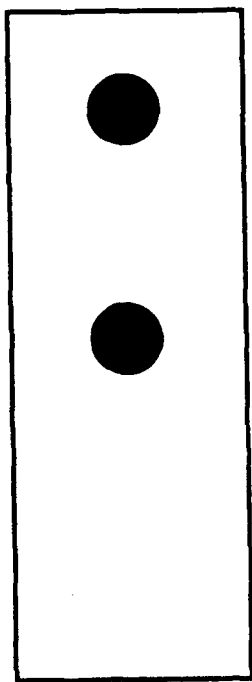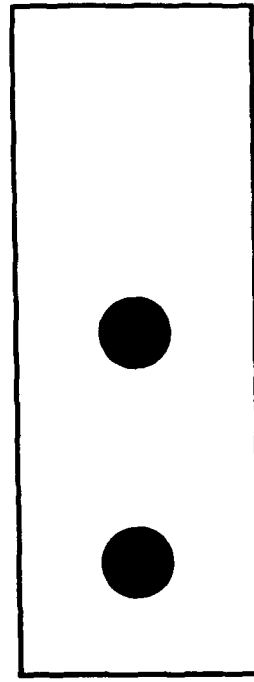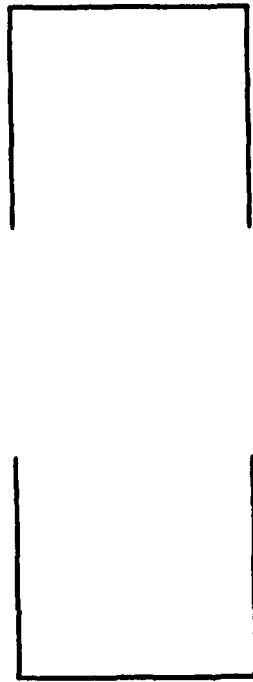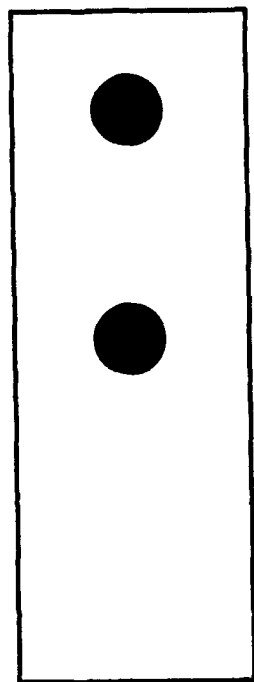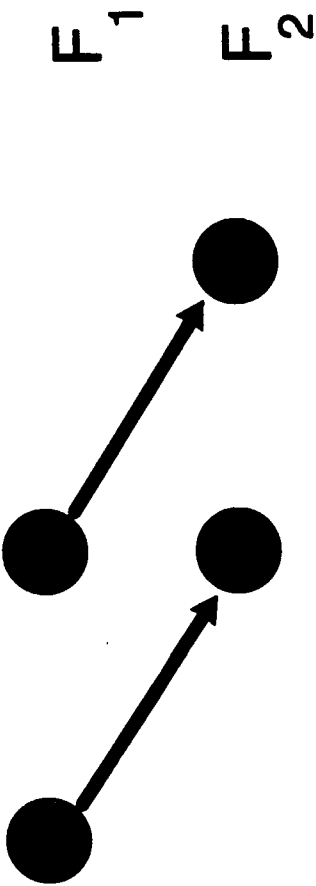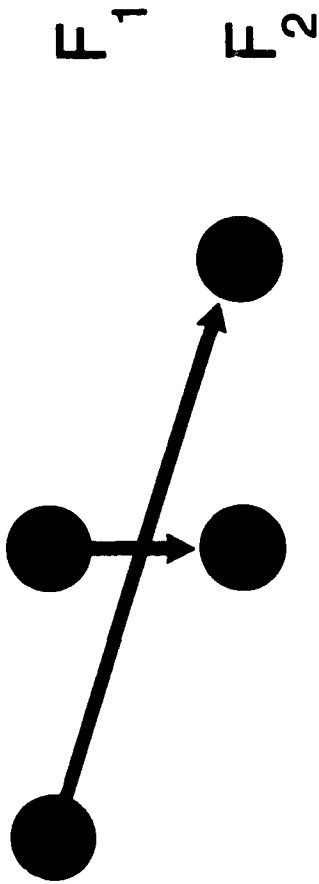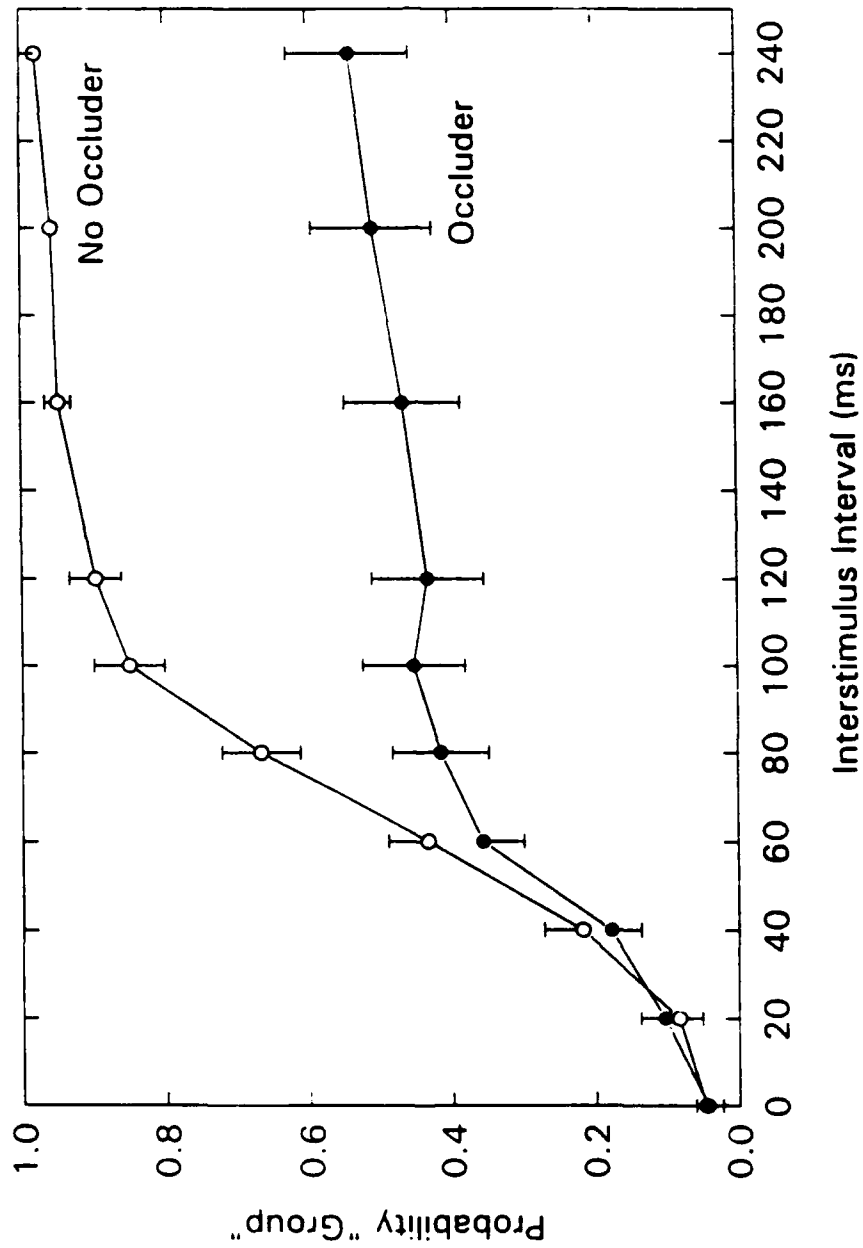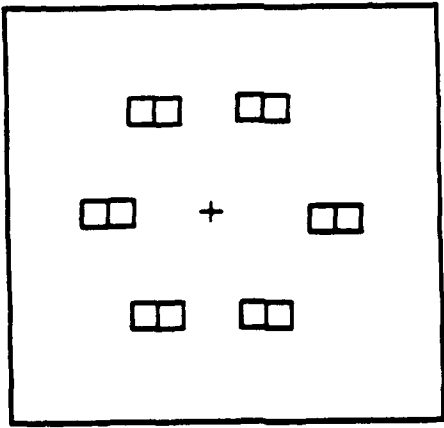
frame 1

ISI

frame 2

Group Motion Correspondences

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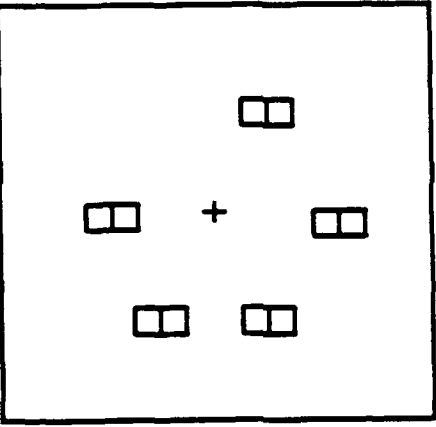
F_2

Element Motion Correspondences

F_1

F_2

fig 2

15 observers
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fig3
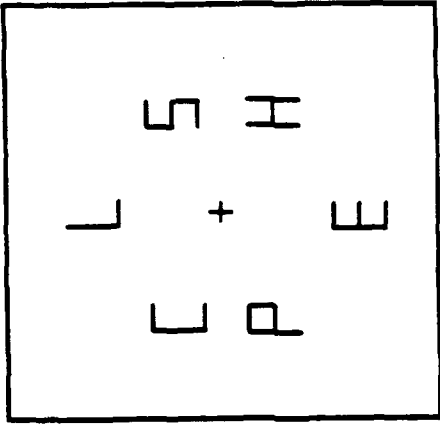
Search Display
Until response

Gap
d (0-200) ms

Placeholders
1000 - d ms

fig 4

Reaction Time

Display Size

No Gap

40-ms Gap

120-ms Gap

No Gap

Gap

fig 5

A

1

2

C

1

2

B

1   2

D

1

2

fig

fig